IAIMS development at Baylor College of Medicine

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At Baylor College of Medicine, we are developing the technical and intellectual resources needed to realize the Integrated Academic Information Management System (IAIMS) concept fully. The substantial technical, organizational, and financial commitments involved demand that we align our efforts with the strategic purposes of the college. The support of science, therefore, has become the principal, but not exclusive, focus of Baylor's IAIMS effort. Even so, the information technology architecture we have created for biomedical research is proving valuable in other settings as well. And the infrastructure we are creating—the communications architecture and the linkages to information resources—serves many purposes in addition to those of research. The architecture accommodates a diversity of workstations, networks, and informational and computational servers. This will be the greatest possible chance of transferring the fruits of our Phase III development to other academic medical centers.

Computers, telecommunications, and related technologies will change radically the ways in which information is acquired and managed in biomedical settings. Powerful analytic programs already are at work in molecular biology; optical disk technology is enriching educational efforts; and the first fruits of artificial intelligence research can be seen in the clinical arena. Little elaboration is required of current trends in information technology to construct some exciting views of the future. We look to the twenty-first century, anticipating impressive applications of computing to the problems of managing information in medicine.

To realize fully the benefits of information technology in the decade to come, academic medical centers need a strategy that can accommodate advances in technology and a number of potentially confounding factors arising from the dynamics of organizational life [1].

At Baylor College of Medicine, we participate in a program sponsored by the National Library of Medicine (NLM) to create an Integrated Academic Information Management System (IAIMS) [2]. This program engages medical centers in a three-stage process: planning for IAIMS development, creating prototype systems, and implementing systems widely within the institution. When fully developed and deployed, IAIMS will offer substantial improvements in information acquisition, sharing, and management to faculty, students, and staff. Baylor College of Medicine is one of four academic medical centers that have reached the third, or implementation, stage of the IAIMS program. We are at work on a broad front to achieve a set of interrelated aims.

THE AIMS OF IAIMS AT BAYLOR

The foundation for advanced IAIMS development at Baylor is an enhanced information technology architecture. The building blocks for this architecture include high-speed networking, improved standards and technology for information management and distribution, and more highly developed means for linking Baylor to its affiliated institutions and regional and national resources.

We are exploiting the IAIMS architecture to increase the productivity of biomedical scientists. The technology spawned by the computer revolution has extended the capabilities of the human intellect in scientific endeavors, and new developments promise to increase the power of that technology by at least an order of magnitude. Major advances in computer architecture, programming, data storage technology,

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computer interfaces, and networks are in the offing. High-speed computation increasingly will become an essential tool of biologists, biochemists, and biophysicists. Our IAIMS architecture, coupled with organizational development, enables us to capitalize on these advances.

Much of our IAIMS development to date has emphasized support for information acquisition, sharing, and management within scientific work groups. Our unique architecture enables us to adapt information technology developed for scientific purposes to educational and administrative applications and to aspects of patient care. With appropriate modifications, that technology can facilitate the work of task-oriented educational teams, such as groups of students and teachers or faculty committees.

In concert with the development of our IAIMS architecture, we are refining organizational processes and components that help us get the most out of our investments. For all their power, computing systems often are complex, and the diversity of applications in a major academic medical institution makes for markedly varied degrees of success. Our IAIMS framework encompasses extensive support for users of information resources and systems.

Finally, we are examining the interplay of information technology, organization, and work in the setting of the academic medical center. While it is clear from the experiences of many institutions that the IAIMS concept will be realized in different ways in different settings, certain aspects of IAIMS development probably are conducive to success. Using a novel approach that employs the techniques of oral history, we are seeking to identify these factors. And we hope to identify aspects of our IAIMS framework that seem most likely to have broad applicability beyond Baylor and the Texas Medical Center.

THE FOCUS ON SCIENCE

Baylor College of Medicine is dedicated to the conquest of disease and the promotion of health through education, research, and service. The college opened in 1900 as the University of Dallas Medical Department and affiliated with Baylor University in Waco in 1903. In 1943, the college relocated to Houston, where it became the first permanent structure of the new Texas Medical Center in 1947. Later, the college separated from Baylor University. Today, Baylor College of Medicine is the only private medical school in the greater Southwest. Baylor is an independent, nonsectarian, nonprofit corporation organized under a self-perpetuating board of trustees. It is located at the hub of the Texas Medical Center, a complex of more than forty independent institutions occupying more than 550 acres.

Baylor College of Medicine offers an M.D. program, a combined M.D./Ph.D. program, and eleven Ph.D. programs. It offers training in twenty-one medical specialties. The college also has a Center for Allied Health Professions and an extensive program in continuing medical education.

While the research, patient care, and teaching activities of the college are intertwined and, through their interaction, determine the character of the institution, we believe scholarly activities will determine in large part Baylor's stature in the biomedical community in the years to come. The generation of new knowledge through vigorous and productive biomedical research will be the single most important factor in our success. Therefore, the primary focus of IAIMS development is the support of science.

The research program at Baylor has expanded dramatically over the past two decades. Baylor now ranks in the top ten medical schools nationally and first among Texas medical schools in competitive federal research funding. The current research and development budget exceeds $130 million.

To strengthen support of biomedical research, Baylor has joined with Rice University to establish an innovative research and training program in computational biology. With the support of the W. M. Keck Foundation, the joint Center for Computational Biology will foster collaboration among biologists, biomedical researchers, and computer scientists and develop and deploy new, more powerful tools for biological research. The Keck Center conducts an innovative training program in computational biology, which is integrated with faculty research programs. Training emphasizes computational aspects of simulation, imaging, and sequence analysis in conjunction with a solid foundation in biophysics, biochemistry, and genetics.

The Keck Center draws on the intellectual and technologic resources of other centers. The Center for Research on Parallel Computation, funded by the National Science Foundation (NSF), ensures that the researchers and programs of the Keck Center have access to advanced ideas and resources for high performance computing. The Human Genome Center at Baylor College of Medicine also has close ties to the Keck Center. Other centers, such as the Three-Dimensional Electron Microscopy Resource Center and the Molecular Biology Information Resource, also provide intellectual and technical resources for the Keck Center.

At Baylor, the activities of the Keck Center are coordinated closely with IAIMS development. The IAIMS architecture integrates a number of innovations in computational biology. NLM recently awarded an Informatics Training Grant in computational biology that will provide trainees with experience in both the Keck Center and IAIMS development. And because there is unified organizational oversight of

IAIMS development, the Keck Center, and the training program, a rich environment can be provided for college faculty and trainees.

THE COMPUTATIONAL ENVIRONMENT

The Baylor Information Network serves as the principal information pathway linking faculty and administrative groups in ten buildings on the Texas Medical Center campus and beyond. Through this network, investigators share research data, clinicians tap hospital information reporting systems, administrators obtain management information and reports, and everyone is able to use a variety of important bibliographic and other scientific information resources. The network has more than 1,000 connections, ranging from personal computers to a variety of intermediate and mainframe computers, and the number of network users approaches 2,000. Demands for access and expanded services are growing, so network development is one of our central concerns.

In 1987, Baylor became a charter member of SesquiNet, a regional network sponsored by the National Science Foundation and developed jointly with Rice University, the University of Houston, and Texas A&M University. Through SesquiNet, the Baylor Information Network is connected to networks at these universities and to an international set of networks known collectively as the Internet.

We also are deploying a high-speed (FDDI) network to connect our computing resources and to link our researchers to the growing national array of high-performance computers.

Clearly, we possess outstanding computational resources to support IAIMS development. In conjunction with the Keck Center, we share a number of advanced parallel computers, including a CM-2 Connection Machine from Thinking Machines and an Intel iPSC 860. A variety of high-performance graphics workstations are available for use by our IAIMS development team.

THE IAIMS ARCHITECTURE

The computing and graphical capabilities underlying advanced biomedical applications are diverse, and it is difficult to assemble them at all the sites where they might be used. As part of our IAIMS development, we created an architecture for the sharing of computational and informational resources across a wide community of scientists. We aim to provide researchers at different sites with access to computing resources that are adequate to meet their requirements, regardless of the location of these resources on the network. The architecture provides a graded degree of support for computation and visualization at workstations, ranging from high-performance models with advanced graphical capabilities to lower-cost time-shared systems with more modest displays. An emphasis on portability helps researchers adapt their software to different computer systems, allowing shifts to more powerful computational platforms as circumstances warrant.

To integrate geographically dispersed resources, we created a layered architectural model that defines how information flows among resources, users, and applications. We emphasize established standards and protocols to integrate resources and increase their utility.

One of the important aspects of our Phase III effort concerns scientific visualization, specifically, the extensive use of advanced computing and graphics to facilitate the representation of the research results. Scientific visualization is a central focus of the Keck Center, and our IAIMS work in this area is coupled with, and supportive of, that focus.

Baylor has a number of centers where advanced computational techniques and equipment are employed for visualization. Because of the specificity and, in certain cases, the idiosyncrasies of the various systems, access is limited. So, despite the sometimes outstanding capabilities available, too few scientists exploit them in their work. Examples are facilities for three-dimensional electron microscopy, magnetic resonance imaging, digital imaging microscopy, and X-ray crystallography. Through IAIMS development, these facilities should become available to larger numbers of interested faculty.

The epitome of our IAIMS architecture is the Virtual Notebook System (VNS), a set of tools for information acquisition, sharing, and integration in user groups. The VNS gives users a set of electronic notebooks based on a distributed, multimedia hypertext system. This has proven to be a powerful way to organize the activities and information of groups.

THE VIRTUAL NOTEBOOK SYSTEM

As its name suggests, the VNS is intended to serve many of the functions of a paper notebook. Indeed, our original idea for the VNS was motivated by the ubiquity of paper laboratory notebooks in biomedical research groups. Using advanced information technology, staff enriched the concept of the notebook to enable members of a team to share and integrate information in their collaborative efforts. Today, although it retains the original concept, the VNS is quite unlike an ordinary notebook. It is a distributed, multimedia hypertext system that transcends many limitations of pencil and paper. Users of the VNS share work with one another through notebooks that any number of group members may own. Notebook owners (and programs) can create information for inclusion on one or more pages of a notebook. In the

simplest case, such information is just text that a notebook owner has typed. Or, it may consist of text and images captured from any other window or program on the user's display. Files also can be pasted into a notebook. And a user with a properly equipped workstation can create audio and video files.

Notebooks are not limited to sequential order; pages may be linked in any order, in a so-called hypertext fashion. Thus, to facilitate sharing of information, a page in one user's notebook may be linked to a page in another user's notebook. Action links perform tasks external to the notebook, such as launching programs that display in windows next to the VNS or playing audio files.

The VNS represents our view of the fully developed IAIMS in its approach to information acquisition, sharing, management, and integration. We developed the VNS in compliance with important standards such as the X-Window System, C, UNIX, and TCP/IP. Our open-system philosophy accommodates technological advances and meets the needs of our users, who operate in heterogeneous computing environments.

The architecture is based on a client–server model in which different layers of the VNS may run on separate platforms that communicate using TCP/IP. The layers consist of a persistent store of information, a transaction manager, the client application, and the user interface.

The use of standard interfaces to networking and stored information enables us to develop additional storage strategies, utilize new network technologies, and support a large number of hardware platforms. For example, the object store has been implemented using both a commercial relational, the Sybase SQL Server, and *ndbm*, a set of database routines available in many UNIX libraries. The resulting flexibility allows us to implement the VNS on databases in existing installations or on newly emerging systems.

The client side of the model links up with the transaction manager through a communications interface library. This library provides a consistent interface for the development of additional applications, which also may communicate with the transaction manager.

The user interface for the VNS is implemented with the X-Window System and the OSF/Motif Toolkit. At present, the VNS runs on Sun Microsystems SPARC, IBM RISC Station 6000, and DEC Ultrix platforms, and can be displayed identically on any X11R4-capable device, such as a workstation, X-terminal, or personal computer. This has been demonstrated successfully on more than twenty different hardware platforms.

The VNS client application supports interclient communications based on the X Window ICCCM. This allows other X client software to send commands to the VNS client application. A programming interface (API) allows applications to create images on a page, change session options, and display pages.

THE IAIMS ARCHITECTURE IN COMPUTATIONAL BIOLOGY

The distinction between the work of the Keck Center and that of IAIMS is largely one of innovation versus distribution. One mission of the Keck Center is to exploit the resources of the Center for Research on Parallel Computation at Rice in creating new approaches and methods for visualization in biology, with particular emphasis on atomic and molecular structure and processes. Dedicated high-performance parallel graphics workstations will serve as the technologic platform.

Beyond advancing the state of the art, however, there is another challenge in scientific visualization, namely, the wide distribution of the tools for the graphic display of the results of various analyses. In Phase III, we are exploiting the IAIMS architecture to restructure visualization tools, to facilitate the distribution of analyses, and to integrate them into the Virtual Notebook. Specifically, for several important facilities, we are restructuring the visualization codes, separating image development from image display and manipulation. By recasting visualization tools in terms of the our IAIMS architecture, we can focus on the development of a standard graphics interface for remote display and manipulation of processed data. Then, the images arising from a particular visualization facility can be transmitted over the Baylor Information Network for local presentation on a workstation remote from the processing site.

Further, to the extent that image display is based in the X-Window System, we can use several different remote platforms. And, by adhering to an interface standard, we can integrate the displayed images into the VNS.

So, in general terms, our approach is to work with several important imaging laboratories at Baylor to separate their image analysis software into analysis and display elements, and to recast the latter to our X-Window System standard. We exploit emerging graphics standards and the supporting transmission and display routines to create network access to the imaging resource in question.

This distribution capability gives faculty access to important elements of advanced visualization capabilities on routinely available hardware platforms. This benefits not only the inexpert user of these facilities, but the experienced scientist as well.

DEPLOYING THE VNS

In Phase III of our IAIMS development, we are deploying the VNS in a number of research settings.

The first is the Division of Neuroscience, a faculty group committed to understanding the structure and function of the central nervous system. These researchers are actively involved in molecular neurobiology, neuroanatomy, neural systems analysis, biophysics, optical imaging, and computer-assisted neural system modeling. This diversity demands special mechanisms for the exchange of information and ideas. The division comprises many laboratories conducting independent research, and they need to share information to enhance collaboration, both within the division and with outside researchers. The VNS helps the scientists manage many of the tasks associated with collaborative science.

At present, about fifty members of the division use the VNS. Within a given lab, some researchers conduct their own projects while other teams work on joint projects. Most researchers keep personal notebooks and provide access in varying degrees to collaborators or others who might find their work interesting.

Much of the sharing through the VNS takes place through common notebooks, which contain important information concerning work in the division. For example, a Chemicals Notebook is shared throughout the entire division. This notebook contains, for each chemical used, its molecular weight, quantity and price information for reordering, and storage location. The division has appointed one person to order all chemicals and maintain the notebook.

Individual laboratories also have developed special notebooks that support the particular experimental processes they employ. One of the common challenges is the integration of new graduate students and postdoctoral fellows into ongoing work. The VNS enables laboratories to distribute their standard operating procedures to all members through the hypertext. Individuals can contribute modifications and improvements based on their experiments.

One lab, for example, has created several such notebooks: the Prokaryotes Notebook, the Vectors Notebook, the Plasmids with Inserts Notebook, and the Protocols Notebook. The content of these notebooks is very technical and specific to neuroscience, so we will describe only two of them briefly. The Protocols Notebook contains the common recipes for conducting experiments. Researchers create navigational links from personal notebooks to the particular protocol they use and make notes on their personal notebook pages about any alterations they make while conducting experiments. The Prokaryotes Notebook contains a complete list of bacteria used in experiments. Again, this notebook provides the researcher with information that does not have to be duplicated each time it is referenced; the researcher merely creates a navigational link to access this information.

Entries in several of these notebooks have action links to external applications, such as one invoking another computer on the network to perform sequence analysis on the particular vector entry or insert. This is an important feature of the VNS for the scientists in this division.

In the coming years, we plan to deploy the VNS in a number of other scientific groups at Baylor and in other academic and administrative settings. To facilitate wide deployment of the VNS, we have developed a variety of programming tools to help create specialized applications for research and clinical settings. We expect a number of trainees in our Informatics Program to use VNS technology to craft computational aids for information acquisition, sharing, and management in various research settings.

While the VNS itself possesses a number of useful capabilities for collaborative work, the system is most useful when it has been tailored to meet the particular needs of a user community. Any two scientific research groups will need different elaborations of the VNS to make the most of their collaborative efforts. Therefore, from the onset, we have incorporated tools within the VNS to allow members of a group to share information in a variety of ways. There is no one way for managing notebooks.

THE IMPACT OF IAIMS DEVELOPMENT

Dramatic advances in computing and related technologies promise to change organizations dramatically. The literature offers many visions of how computing may restructure organizational life. New technology for acquiring, managing, and sharing information certainly will reshape the workplace. But the effect will be determined by more than the technology alone. Computing will call forth new behaviors and induce new organizational patterns, probably ranging beyond current presumptions.

We expect the VNS to enhance the sharing of information and ideas in and among labs at Baylor through common electronic notebooks containing ideas and results of experiments. In collaborative experiments, the VNS provides a mechanism, through the creation of shared pages, for immediate feedback of results. The notebook also provides access to data obtained in labs with different research programs. Finally, the VNS facilitates compilation of diverse data for manuscripts, literature references, results of specific experiments, methods, and graphics and images.

In recent years, IAIMS development has become a matter of great interest to the leaders of academic medical centers. The rapid development of information technology suggests profound changes in the nature and conduct of biomedical research, patient care, and education. One of the paramount goals of IAIMS is to integrate information technology in its

various forms into academic and administrative programs. The extent to which integration takes place and the benefits that accrue are important elements of evaluative inquiry.

The development of IAIMS poses a formidable challenge to any academic medical center. The effort and commitment required to reach the level of information management envisioned for the fully articulated IAIMS concept is considerable. To succeed, the institution needs to muster an impressive array of technologic and intellectual resources and may need to make far-ranging organizational changes. The details and significance of these changes also should be subjects of evaluation.

At Baylor, we are using the techniques of oral history to record the responses of faculty and staff to VNS as we deploy it in various collaborative settings. Oral history is a research technique which centers on the use and preservation of tape-recorded interviews for obtaining first-person accounts of how modern society has been shaped by causative factors of historical significance. Oral history is capturing and preserving the "human voices" of Baylor's IAIMS effort. Even in the first of five years of our planned IAIMS implementation, the oral history interviews give insights into the impact of technology on biomedical research procedures.

For many leaders of academic medical centers, understanding the experience people have with technology is vital; they seek testimony on how computing is reshaping science, education, and other activities. Such testimony, properly obtained and organized, can be one of the major contributions of the IAIMS process. Oral historians, working within this rich environment, can elicit valuable insights into the processes by which people confront powerful new technology. Oral history is an innovative and suitable technique for ascertaining how people can be productive workers in a biomedical research environment in which advanced information technology plays a vital role.

THE INFORMATION TECHNOLOGY PROGRAM

Because Baylor College of Medicine aspires to preeminence in biomedicine, it must make effective use of advanced information technology. To realize the level of technology development embodied in the IAIMS concept, the Information Technology Program was created, which contributes substantial human and technical resources sustained with college funds.

This program has evolved with the changing needs of the IAIMS effort. The faculty and staff's increased need for consulting led to creation of the Computing Resource Center, and a growing need for technical support resulted in the Systems Support Center. To integrate our information services, Baylor has placed increased emphasis on project teams. These teams have demonstrated the technical and organizational competence to carry IAIMS to an advanced level.

In recent years, the IAIMS framework has absorbed the administrative computing functions of the college. Many administrative functions are important to the direct support of academic endeavors, and as a result, a fully developed IAIMS should encompass administrative computing. As a result, administrative systems are moving toward networked, distributed computing involved extensively with relational database technology and with the client-server model. During Phase III development, we expect to convert certain aspects of our administrative computing to the X-Window System. Important components of the administrative computing network already can be integrated into the Virtual Notebook System.

The IAIMS concept guides the development of the Information Technology Program. While the form of the program will continue to change, its purpose remains constant: to provide the highest quality information technology support to the academic and administrative programs of Baylor College of Medicine.

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